CMPT 321
Introduction to databases

Fall 2017

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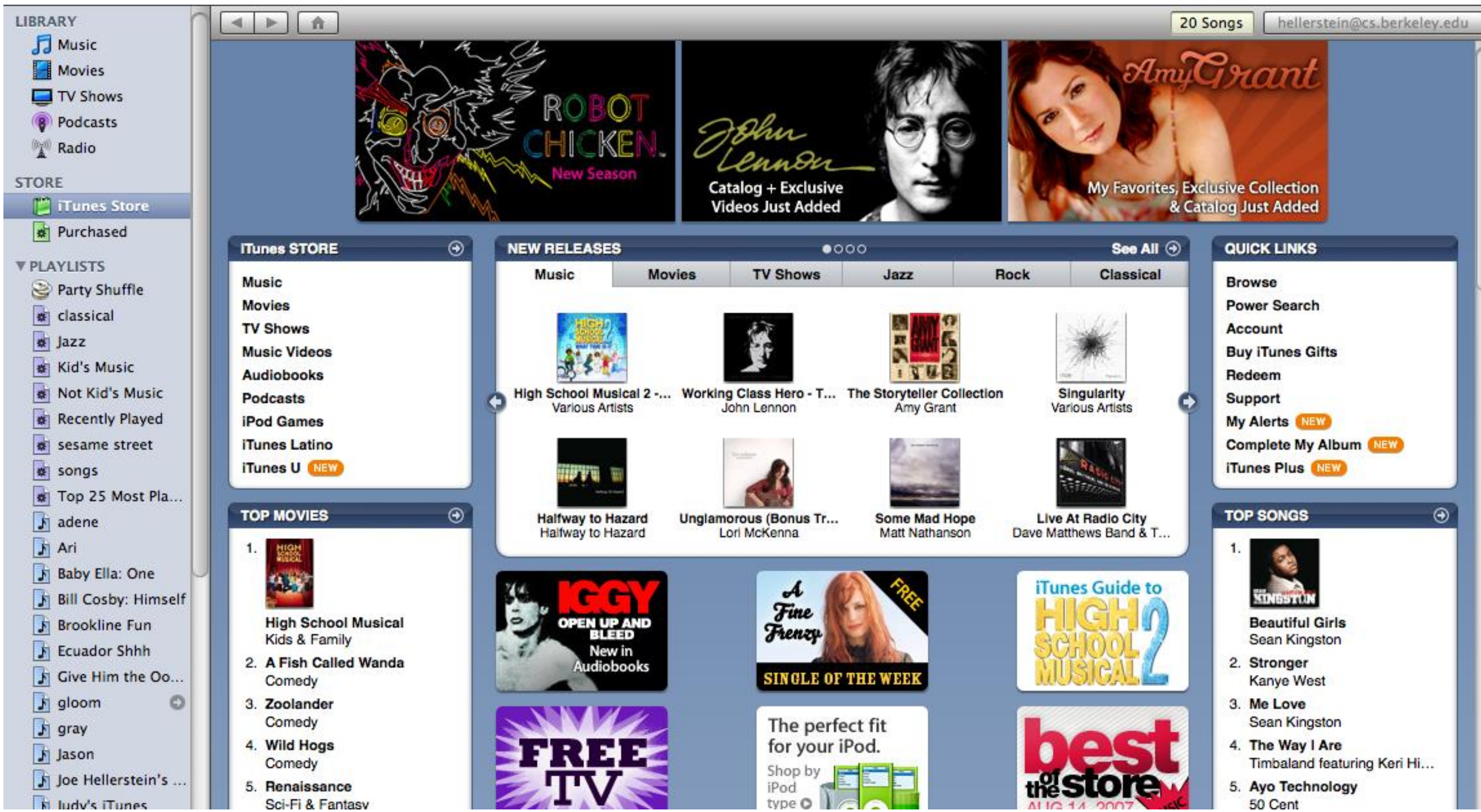
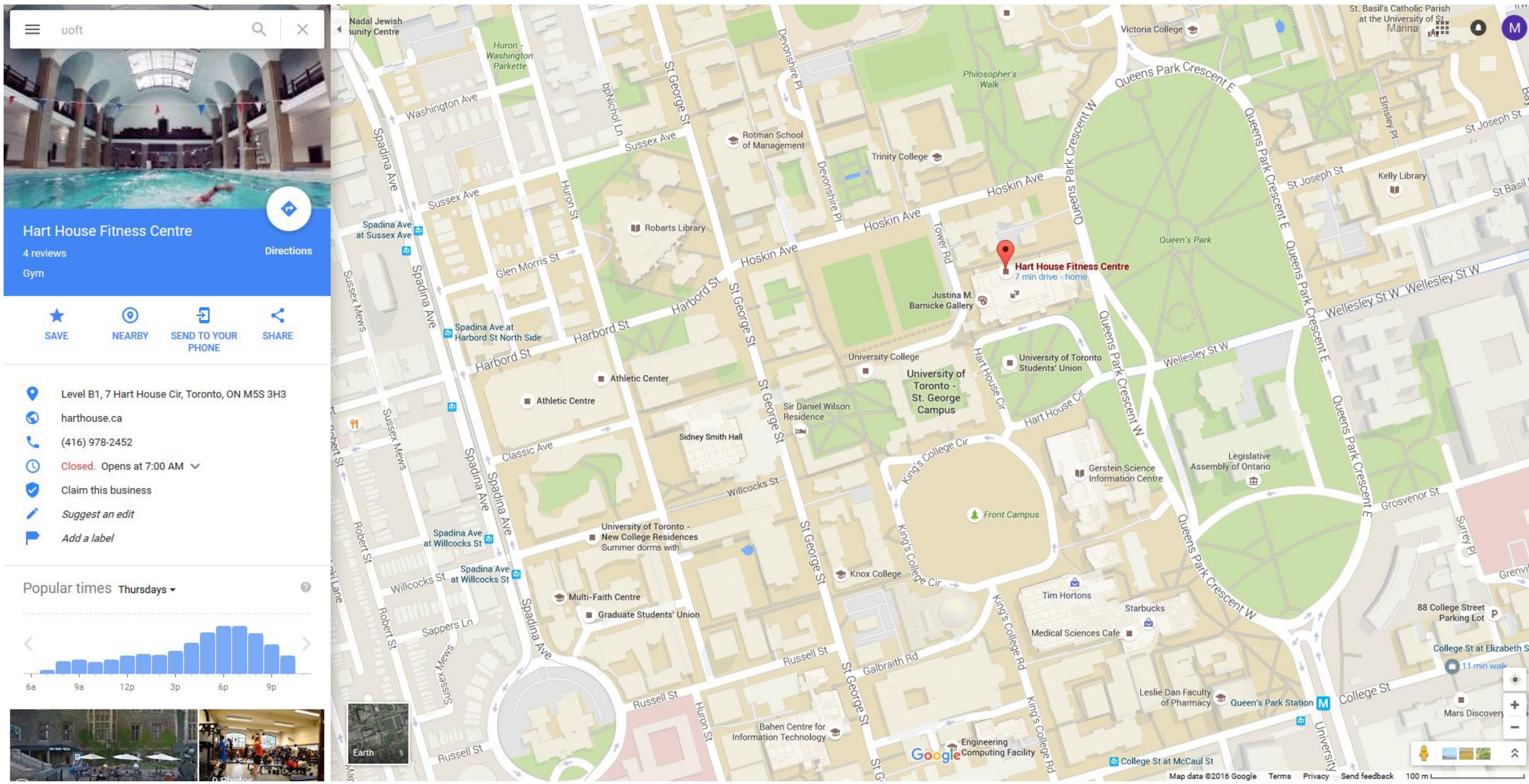
The data world

- We aggressively acquire data and keep it forever
- The real freedom is when we have access to all the data
- The goal – preserve knowledge and make it accessible to everyone
- More ambitious goal – enough data that we can simulate real world and understand its behaviour from these simulations

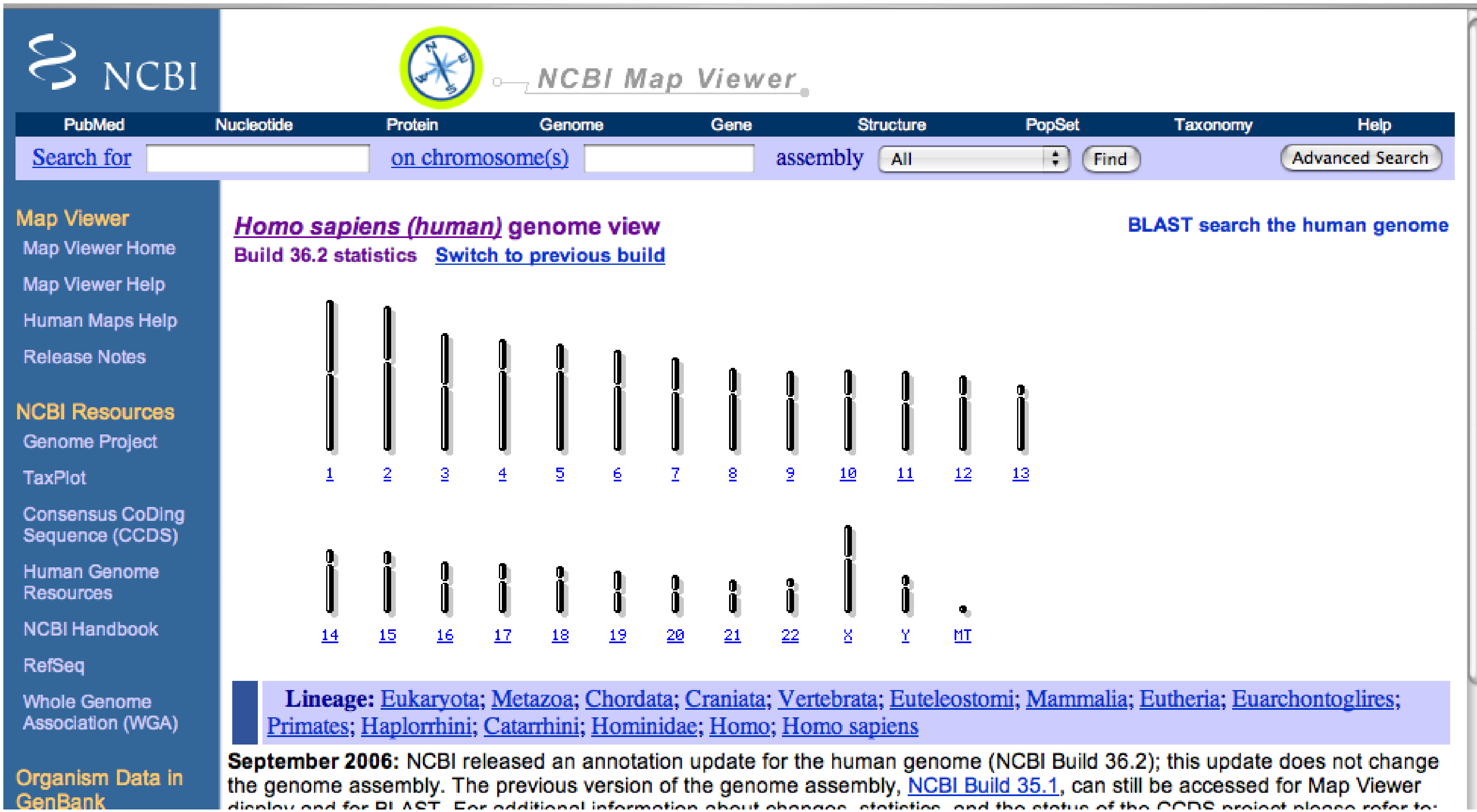
Types of data: music



Types of data: geodata



Types of data: bio-sequences



“Big data”?

- Basic demographic information—age, sex, income, ethnicity, language, religion, housing status, and location—of every living human being on the planet can be stored in 100GB
- This would create a table of 6.75 billion rows and 10 columns.
- Should that be considered “big data”?

From “Pathologies of Big Data” Article by Adam Jacobs in the ACM Communications, August 2009.

Data Units

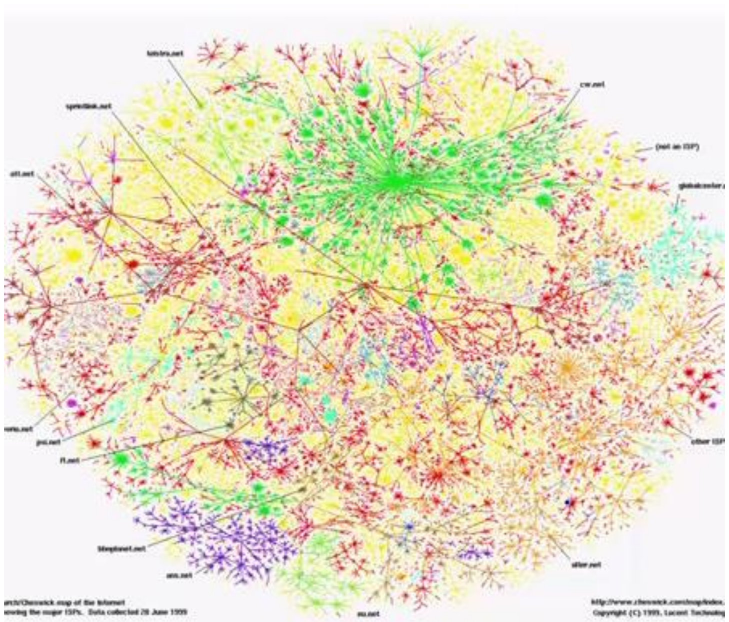
Roughly:

K	Kilo	2^{10}	10^{3}
M	Mega	2^{20}	10^{6}
G	Giga	2^{30}	10^{9}
T	Tera	2^{40}	10^{12}
P	Peta	2^{50}	10^{15}

Example: Volume

- The web
  - 20+ billion web pages x 20KB = 400+ TB
  - One computer can read 30-35 MB/sec from one disk – 4 months just to read the web

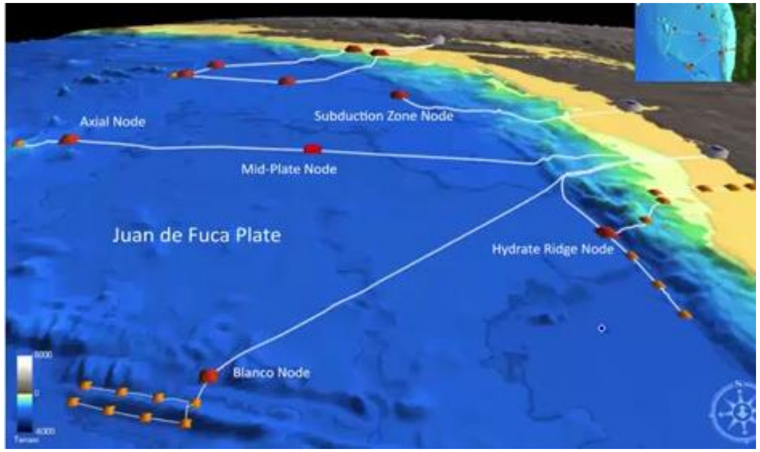
The web



Example: Variety

- NSF Ocean Observatories Initiative
  - Data is collected from satellites, vessels, censors
  - 1000 km of optic cable on the seafloor with thousands of chemical, physical, biological sensors
  - 50 TB/year of different data types

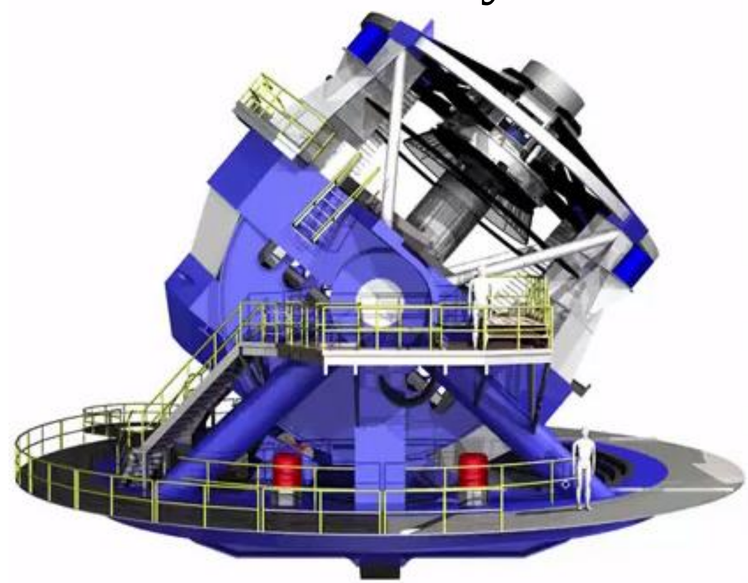
Ocean Sciences



Example: Velocity

- Large Synoptic Survey Telescope (LSST)
  - 40 TB/day
  - 40+ PB in its 10 year lifetime
  - 400 mbps sustained data exchange rate between Chile and NSCA
- Largest database in the world: World Data Centre for Climate (WDCC):
  - 100 TB of sensor data/year
  - 110 TB of simulation data/year
  - 6PB of additional information stored on tapes

Astronomy



Big Data: 4V

- **V**olume
- **V**ariety
- **V**elocity

- **V**eracity: can we trust this data?

Evolution of Science

- Empirical Science – collect and systematize facts
- Theoretical Science – formulate theories and empirically test them
- Computational Science – run automatic proofs, simulations
- **e-Science** (Data Science) – collect data without clear goal - and test theories, find patterns **in the data itself**

Science is about asking questions

Traditionally: "Query the world"

Data acquisition for a specific hypotheses

Data science: "Download the world"

Data acquired en masse in support of future hypotheses

Computational challenge

The cost of data acquisition has dropped

The cost of **processing**, **integrating** and **analyzing** data is the new bottleneck

"…the necessity of grappling with Big Data, and the desirability of unlocking the information hidden within it, is now a key theme in all the sciences – arguably the key scientific theme of our times"

F. Diebold

Efficient data manipulation

Poll: How much time modern scientists spend "handling data" as opposed to "doing science"?

Mode answer: 90%

*"the Next Wave of InfraSress" (*J. Mashey)

Raw data ≠ knowledge!

We need to store data in a system that provides:

- **Non-volatile** **reliable** storage
- Organized for **efficient** queries of any kind

Is a File System a candidate?

Thought Experiment 1:

- You and your project partner are editing the same file.
- You both save it at the same time.
- Whose changes survive?

A) Yours B) Partner's C) Both D) Neither E) ???

Is a File System a candidate?

Thought Experiment 2:

- You're updating a file.
- The power goes out.
- Which changes survive?

A) All B) None C) All Since Last Save D) ???

Is a File System a candidate?

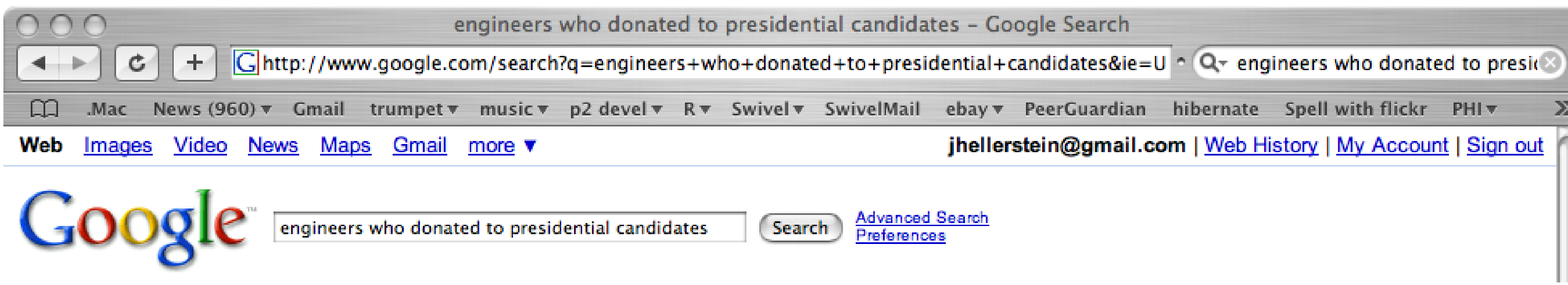
Q: How do you write programs over a subsystem when it promises you only "???" ?

Is the WWW a candidate?

- Crawler indexes pages on the web and we can search for pages by keyword
- Source data is mostly "prose": *unstructured* and untyped
- Public interface is *search only*:
  - can't modify the data
  - can't get summaries, complex combinations of data
- Few guarantees provided for freshness of data, consistency across data items, fault tolerance, …

“Search” vs. Query

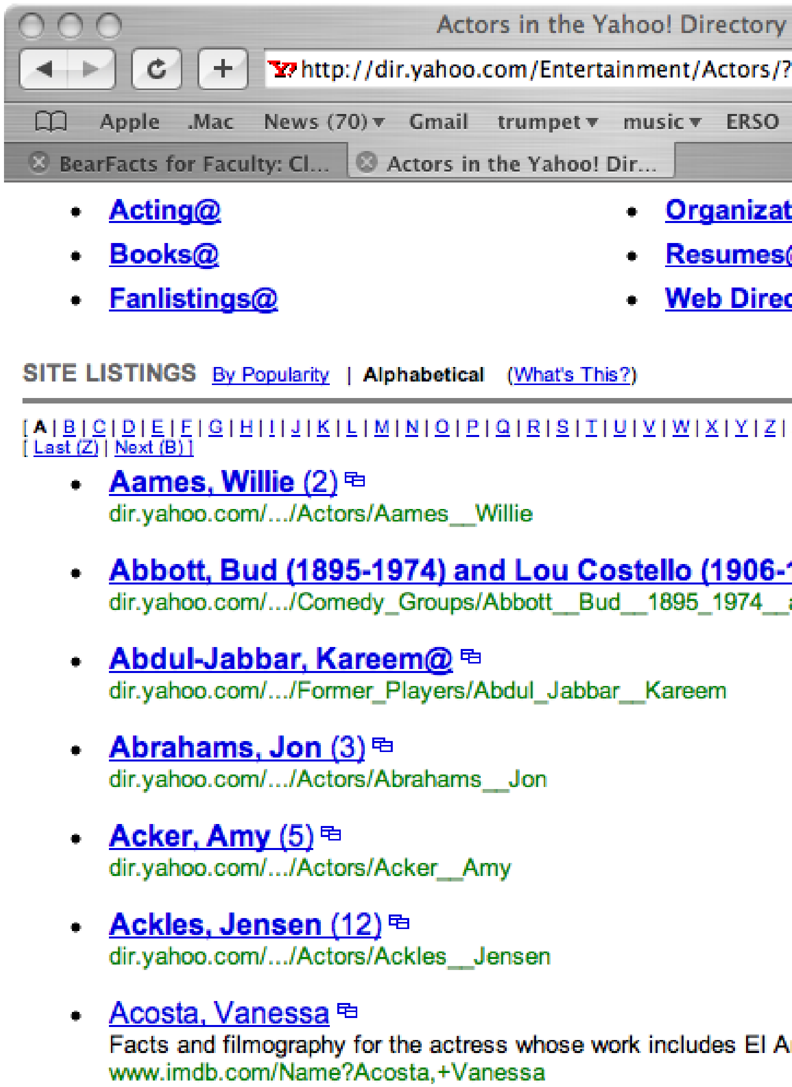
- Try *actors who donated to presidential candidates* in your favorite search engine.
- Now try *engineers who donated to presidential candidates*



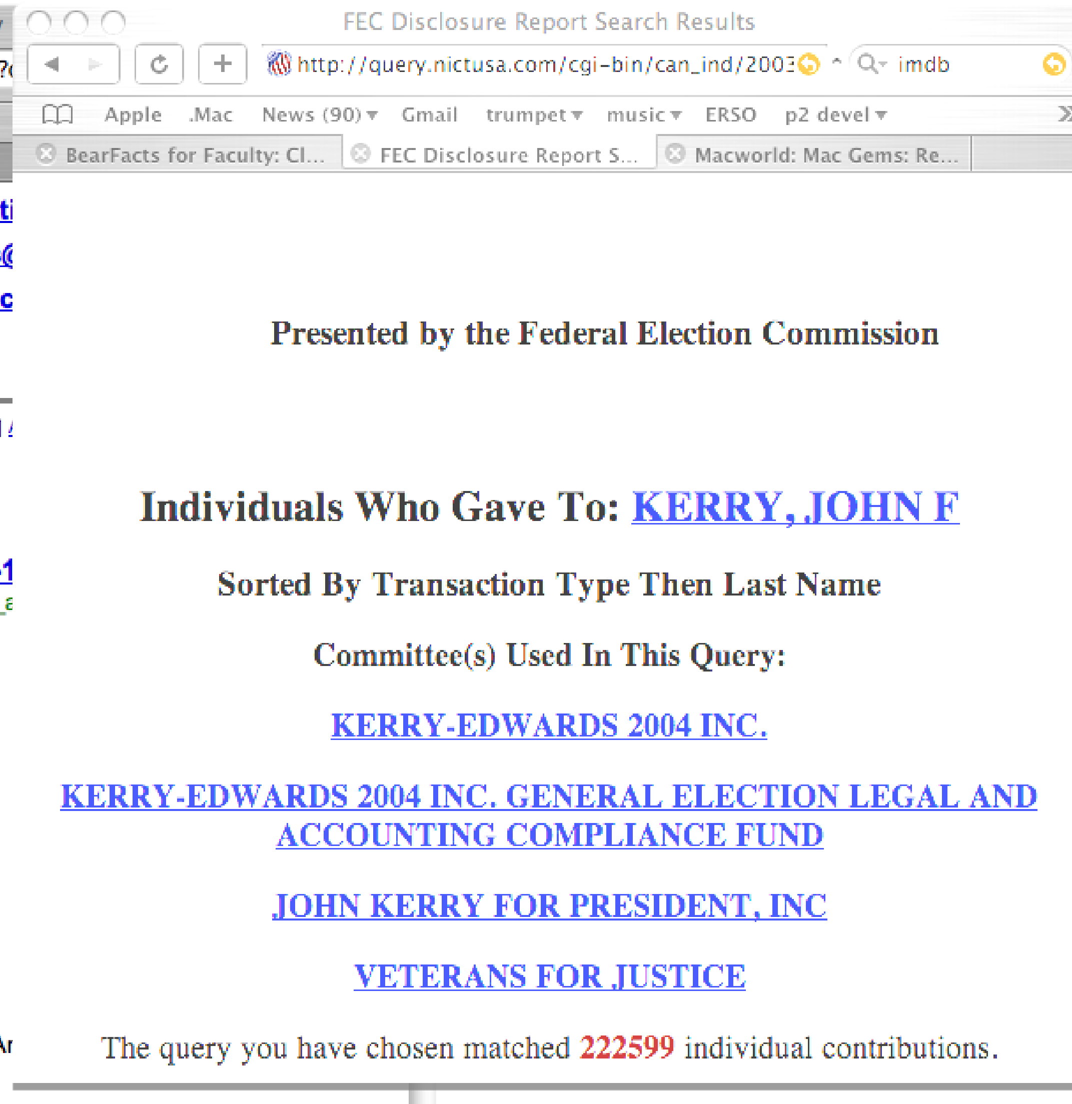
If it isn’t “structured”, it can’t be searched!

A “Database Query” Approach

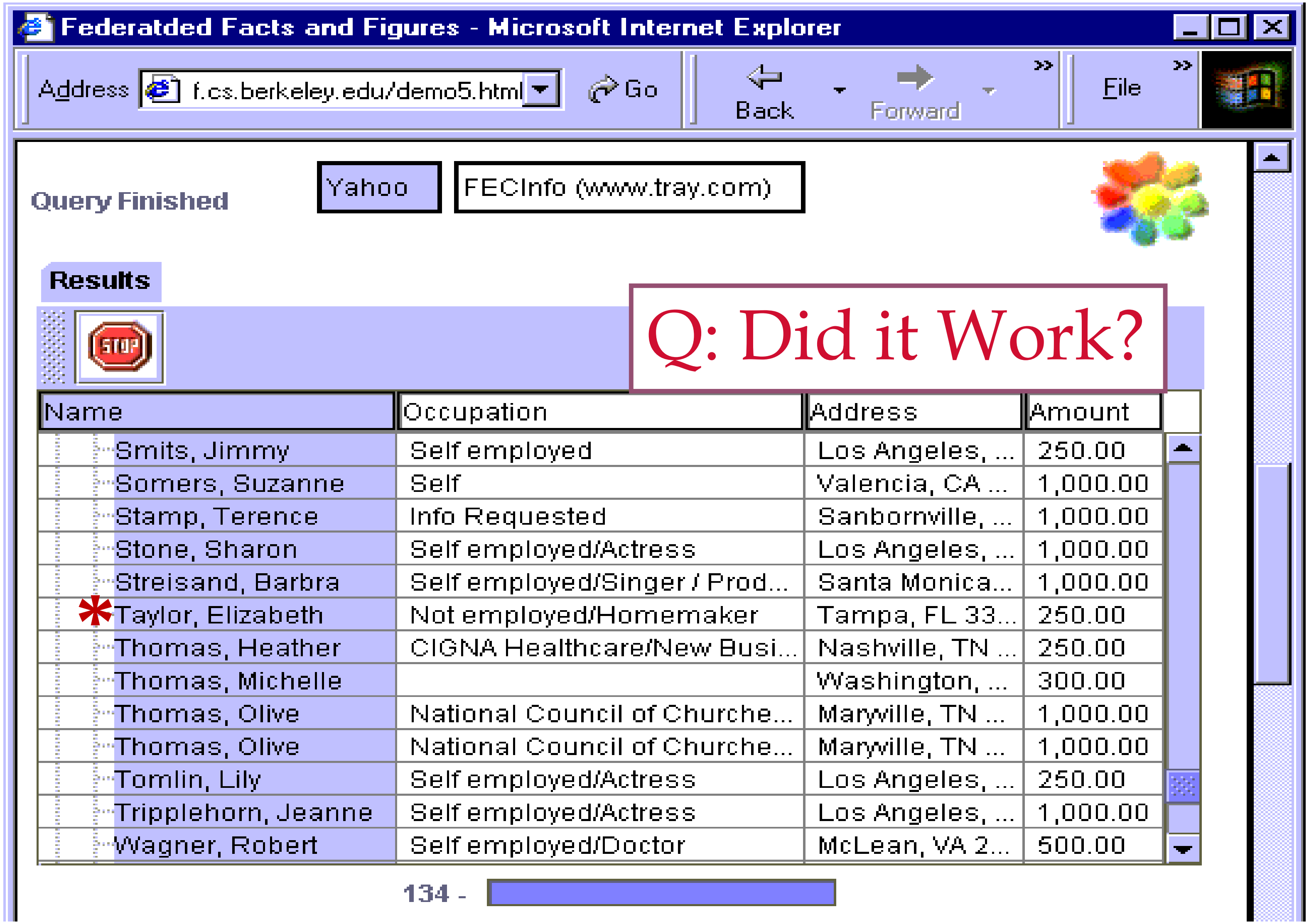
Actors dataset



Donors dataset



“Yahoo Actors” JOIN “FECInfo”



Name	Occupation	Address	Amount
Smits, Jimmy	Self employed	Los Angeles, ...	250.00
Somers, Suzanne	Self	Valencia, CA ...	1,000.00
Stamp, Terence	Info Requested	Sanbornville, ...	1,000.00
Stone, Sharon	Self employed/Actress	Los Angeles, ...	1,000.00
Streisand, Barbra	Self employed/Singer / Prod...	Santa Monica...	1,000.00
* Taylor, Elizabeth	Not employed/Homemaker	Tampa, FL 33...	250.00
Thomas, Heather	CIGNA Healthcare/New Busi...	Nashville, TN ...	250.00
Thomas, Michelle		Washington, ...	300.00
Thomas, Olive	National Council of Churche...	Maryville, TN ...	1,000.00
Thomas, Olive	National Council of Churche...	Maryville, TN ...	1,000.00
Tomlin, Lily	Self employed/Actress	Los Angeles, ...	250.00
Tripplehorn, Jeanne	Self employed/Actress	Los Angeles, ...	1,000.00
Wagner, Robert	Self employed/Doctor	McLean, VA 2...	500.00

(From Telegraph research group @Berkeley)

To have a real data management system we need to solve problems of:

- **Scale**: data exceeds main memory, specialized (quite complex) EM algorithms, efficiently implemented
- **Sharing**: using the same data by multiple user programs simultaneously (concurrently)
- **Fault-tolerance**: avoiding data loss
- **Consistency**: clean consistent snapshots of data, reinforcing data constraints

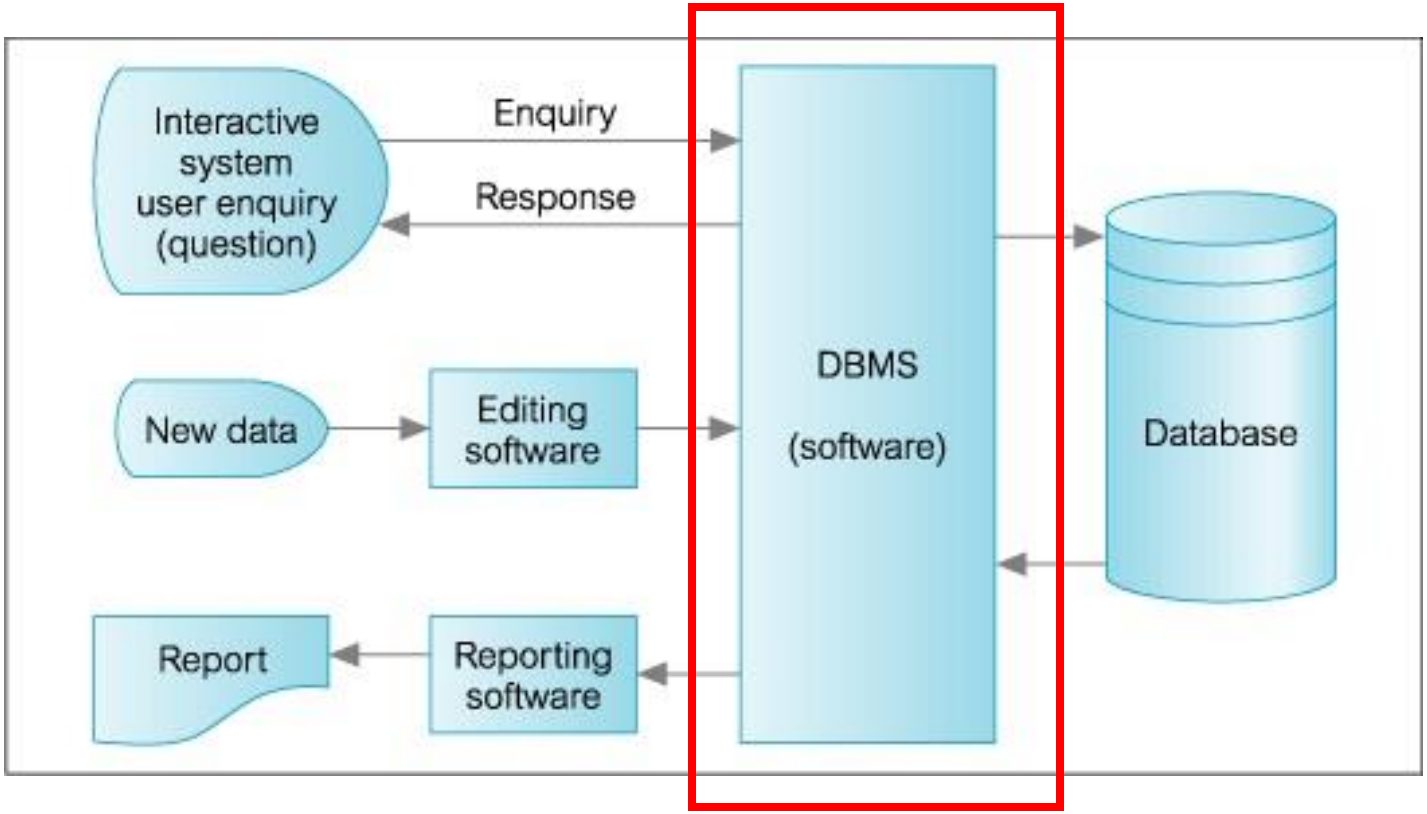
Our dream system:

1. Allows to create new data collections and specify their schema (logical structure of the data) in a simple language
2. Enables data query and modification, using a simple language
3. Supports intelligent storage of very large amounts of data.
    a. Enforcing constraints (to not allow the insertion of two different people with the same SIN).
    b. Efficient access to the data for queries and modifications (Indexes).
4. Controls access to data from many users at once (concurrency), without allowing “bad” interactions that can corrupt the consistency.
5. Recovers from software failures and hardware crashes.

Such system exists:

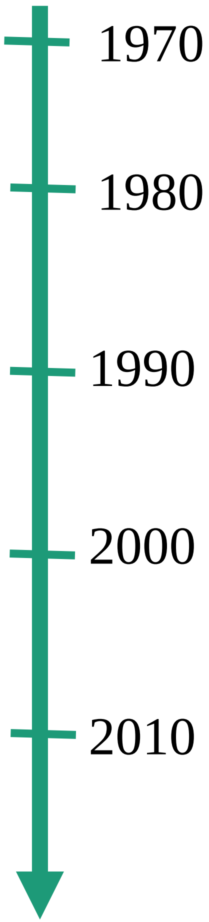
Database Management System (DBMS) - complex *software* for storing and managing databases.

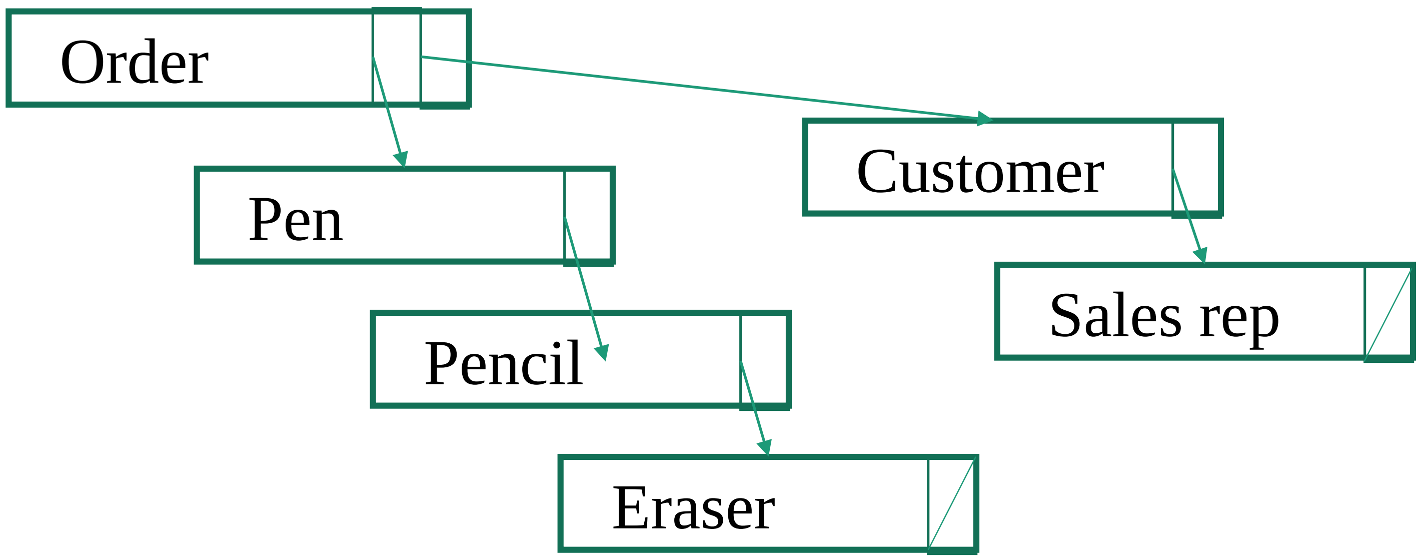
Database management system



History of DBMS

Network databases

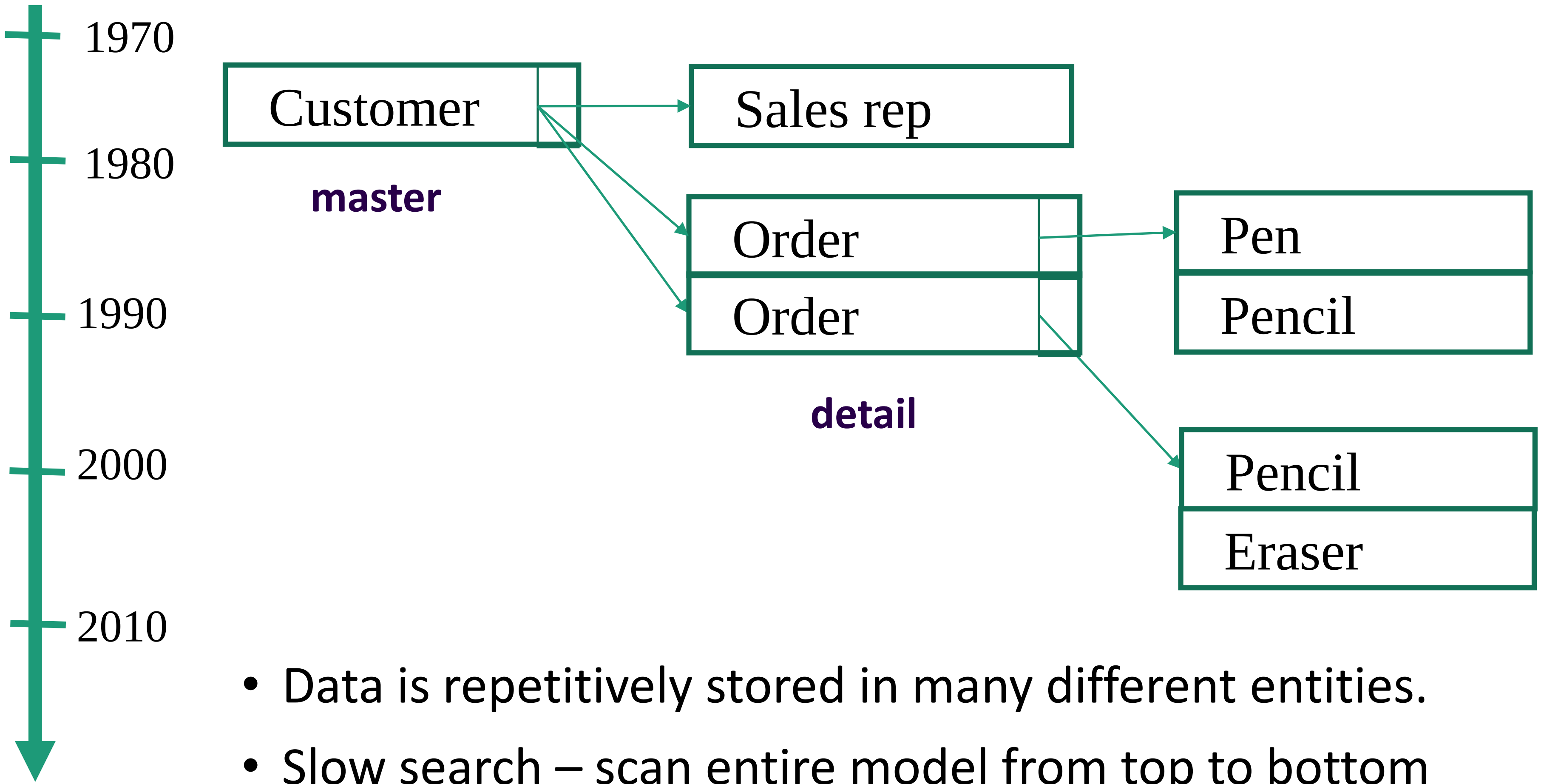




- Insertions, updates, and deletions are complex and inefficient
- Lack of Data Independence: a change in structure demands a change in the application
- Unanticipated queries cannot be performed efficiently

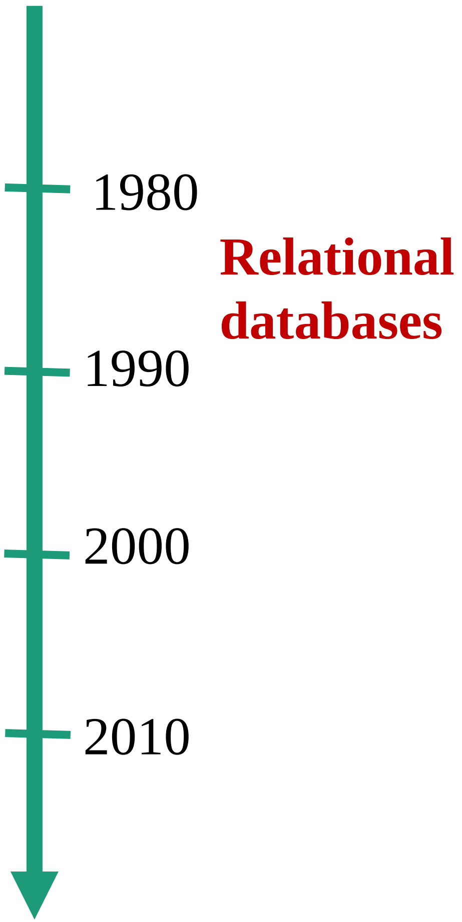
History of DBMS

Hierarchical databases



- Data is repetitively stored in many different entities.
- Slow search – scan entire model from top to bottom
- One-to-many relationships only

History of DBMS



God made the integers;

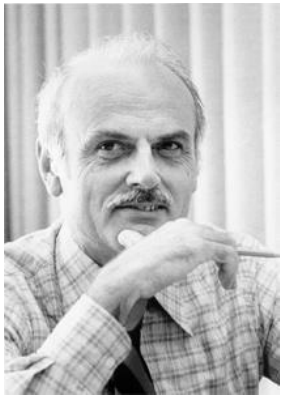
all else is the work of man.

L. Kronecker, 19-th century mathematician

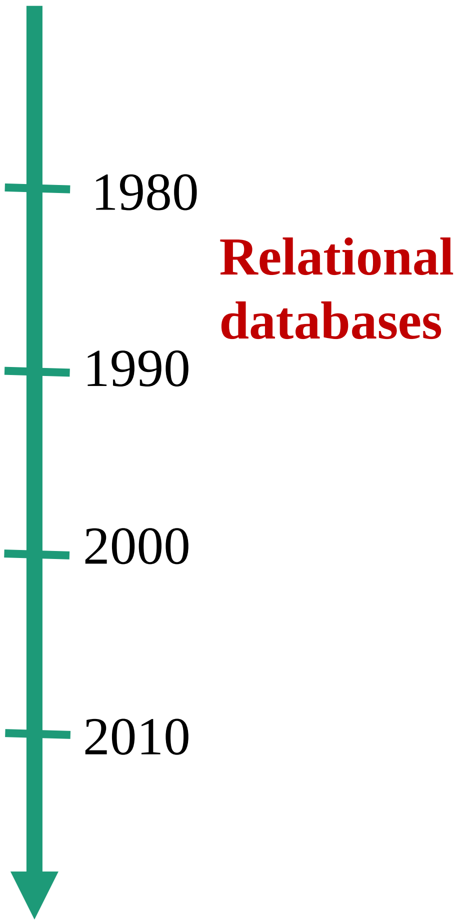
Codd made relations;

all else is the work of man.

R. Ramakrishnan



History of DBMS



Think in terms of tables, not bits on disk.

"Activities of users at terminals ***should remain unaffected when the internal representation of data is changed***."

- Pre-relational: if your data changed, your application broke
- Early RDBMSs were buggy and slow, but required only 5% of the application code

Ted Codd’s vision

- A database system should present the user with a view of data organized as tables (also called *relations*).

- Behind the scene there could be a complex data structure that allows rapid response to a variety of queries. But the user would not be concerned with the storage structure.

- Queries could be expressed in a very high-level language, which greatly increases the efficiency of database programmers.

Relational databases: key idea

Programs that manipulate tabular data exhibit an *algebraic structure* allowing reasoning and manipulation independently of physical data representation

Can apply relational algebra!

Algebraic optimization: symbolic reasoning on integers

N = ((z*2) + ((z*3) + 0))/1

Algebraic laws:

1. Identity: x+0 = x
2. Identity: x/1 = x
3. Distributive: ax + ay = a*(x+y)
4. Commutative: x*y = y*x

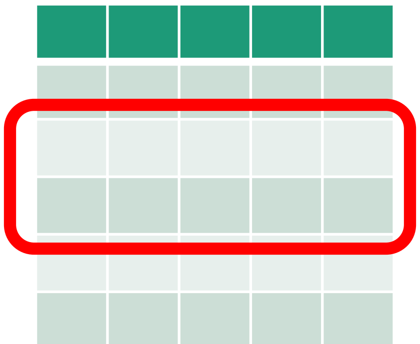
Apply rules 1,3,4,2:

N = (2+3)*z

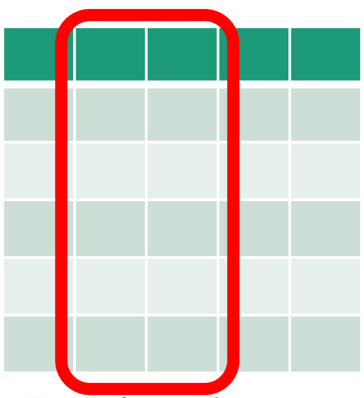
One operation instead of five, no division.
Closure: each operation returns the value of the same type, so operations can be chained

Same idea works with relational algebra!

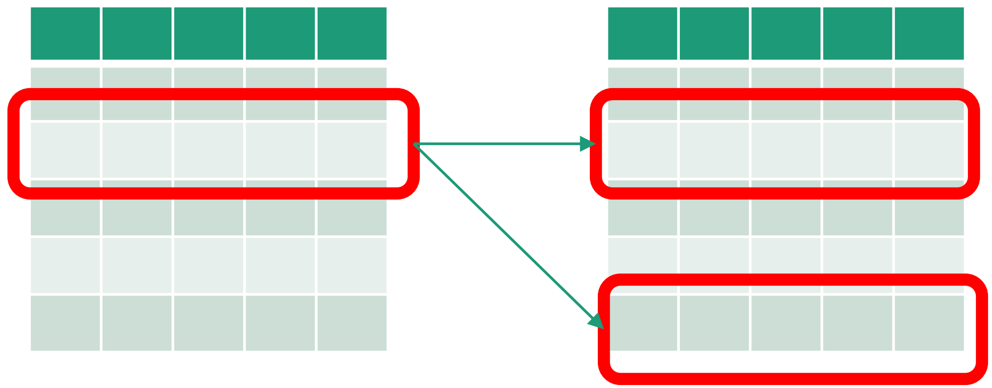
Algebra of tables



Selection σ



Projection π



Join ⋈

Cross-product x

Union ∪

Difference –

Intersection ∩

Case in favor of Relational Database Management Systems

RDBMS provides:

- Physical and logical data independence
- Automatic indexing
- Efficient implementation of RA operators
- Query optimization
- Support and guarantees of atomic transactions

Imagine adding all these features yourself for your next data product!

Early applications of RDBMS's

- Airline reservation systems
- Banking systems
- Corporate records

Data composed of many small items, and various queries and modifications on them.

Example: RDBMS vs Files

- Suppose we have stored in a file called *Employees* records having the fields

  (emp_code, name, dept_code)

- and in another file called *Departments* records having the fields:

  (dept_code, dept_name)

Suppose now that given an employee, for instance with name "Smith", we want to find out what department is he working for.

Files: solution

In the absence of DBMS we have to *write a program* which will:

1. open the file Employees
2. declare a variable of the same type as the records stored in the file
3. scan the file:

    while the end of the file is not yet encountered,

        assign the current record to above variable.

        if the value of the name field is "Smith" then remember the value of the dept_code field. Suppose it is "100"

4. search in a similar way for a record with "100" for the dept_code in the Department file.
5. print the dept_name when successfully finding the dept_code.

Very painful procedure

Modern RDBMS solution

Compare it to the short and elegant SQL query

```
SELECT    dept_name
FROM      Employees, Department
WHERE     Employees.name="Smith" AND
          Employees.dept_code = Department.dept_code
```

Example: Query optimization

SELECT Accounts.balance

FROM Customers, Accounts

WHERE Customers.SIN = Accounts.SIN **AND** Customers.name = 'Sally';

This query - if executed naively:

- Pairs tuples of tables specified in the **FROM**-clause into a new table **R**.
- Chooses from **R** the tuples satisfying the condition in the **WHERE** clause.
- Produces as answer only the values of attributes in **SELECT**-clause.

The performance would be terrible, because of the usually enormous (quadratic) size of all pairs of tuples.

Example: Query optimization

SELECT Accounts.balance

FROM Customers, Accounts

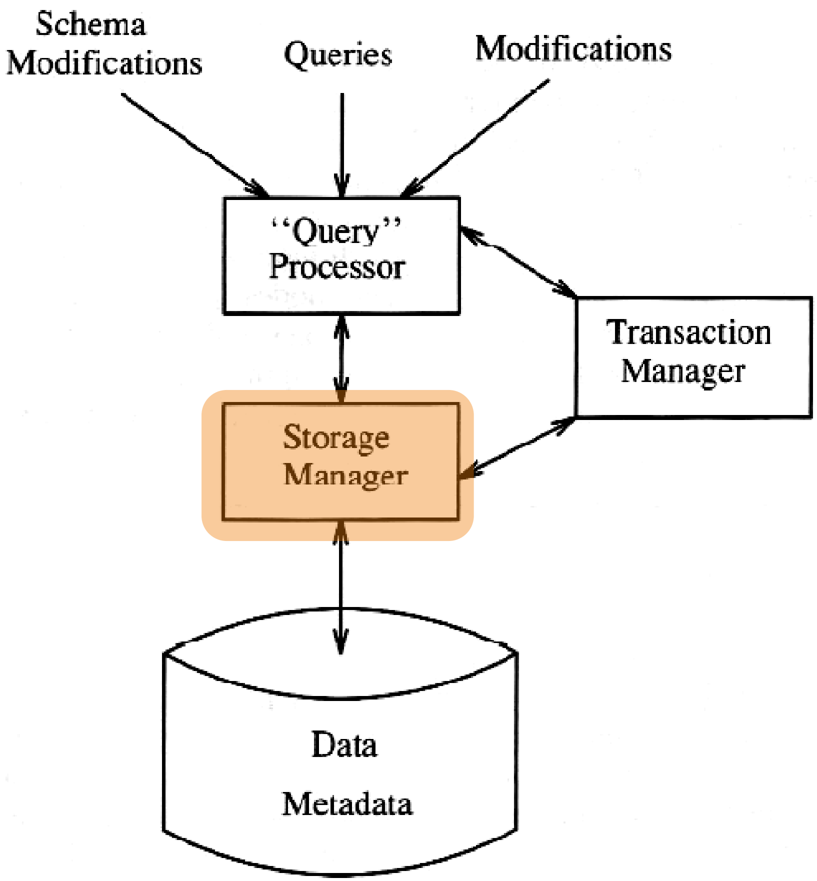
WHERE Customers.SIN = Accounts.SIN **AND** Customers.name = 'Sally';

Query processor will cleverly create a plan which inexpensively:

- Retrieves the tuple for "Sally" and gets the SIN number
- Retrieves the account tuples for this SIN number

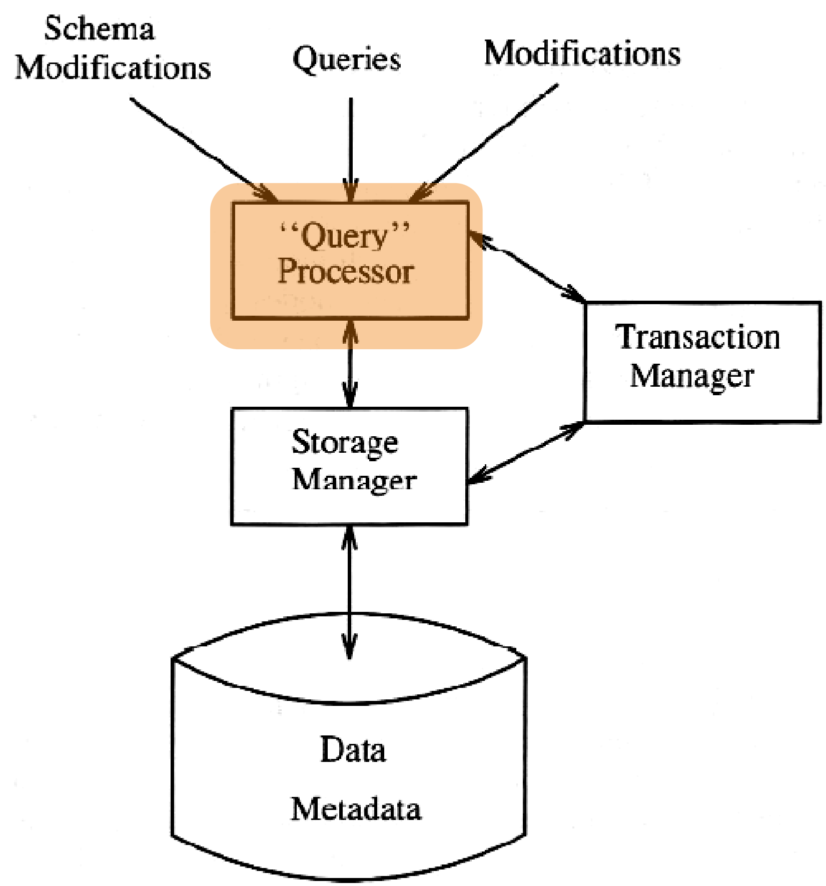
RDBMS: data consistency

- Write Ahead Logging – full recovery from failures



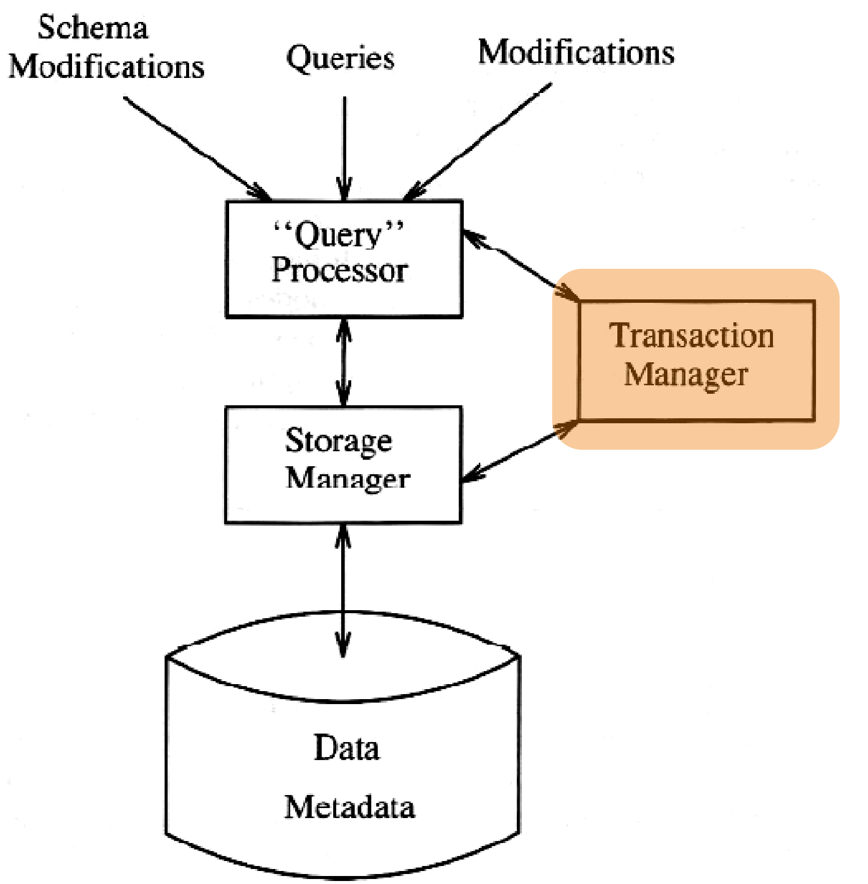
RDBMS: efficient query implementation

- Implements each operation using the most efficient EM algorithm
- Computes the best way to carry out a requested operation using relational algebra and statistics



RDBMS: concurrent execution

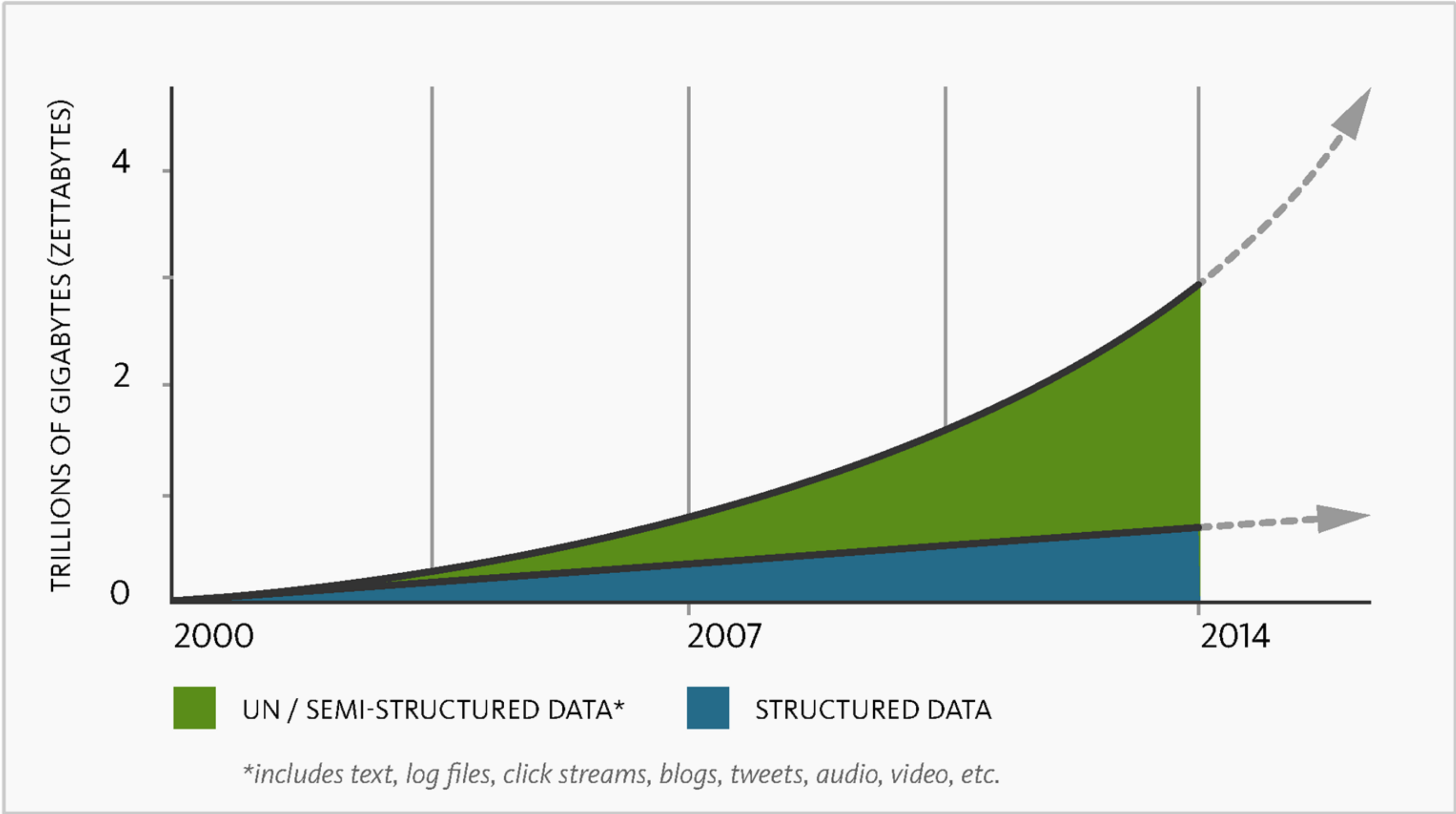
- Assures that several queries running simultaneously do not interfere with each other and that the system will not end up in an inconsistent state



RDBMS is a very complex system

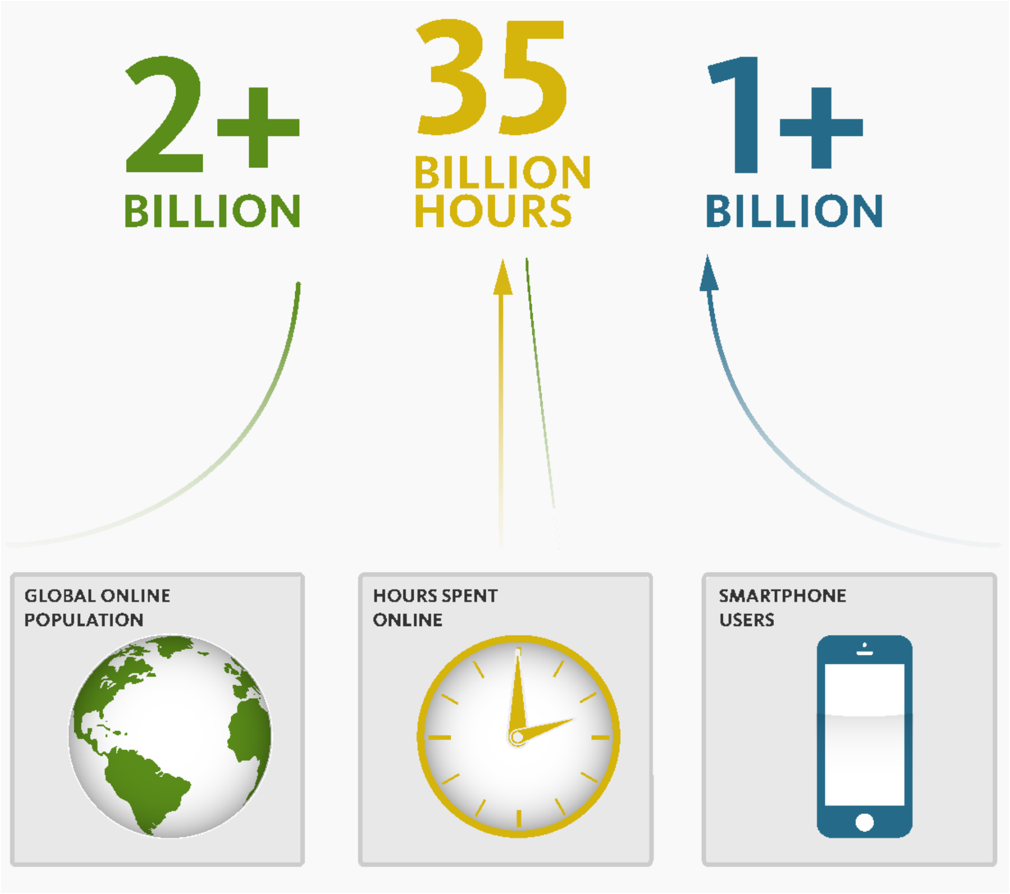
Good news: it has been already implemented for you to use

Current Trends: Big Data



source: http://www.couchbase.com/sites/default/files/uploads/all/whitepapers/NoSQL-Whitepaper.pdf

Current Trends: Lots of traffic



source: http://www.couchbase.com/sites/default/files/uploads/all/whitepapers/NoSQL-Whitepaper.pdf

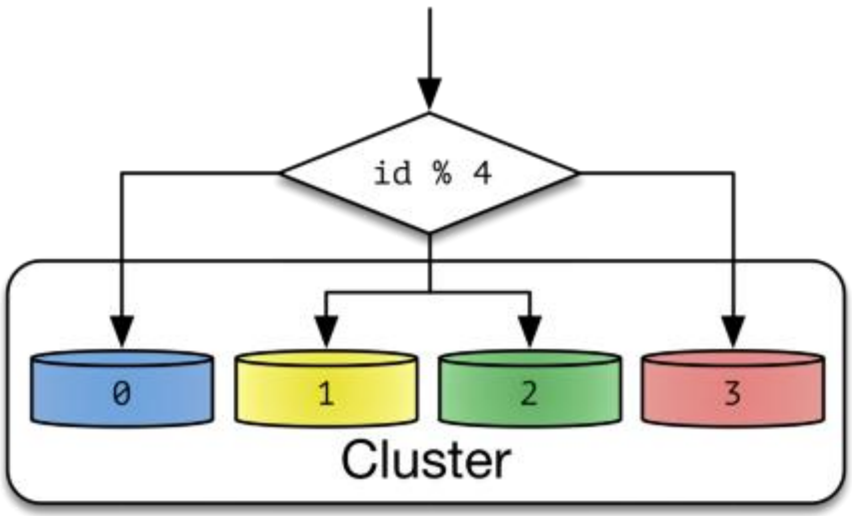
Current Trends: Cloud Computing

source: http://www.profitbricks.com/what-is-iaas

Scaling up

Two alternatives:

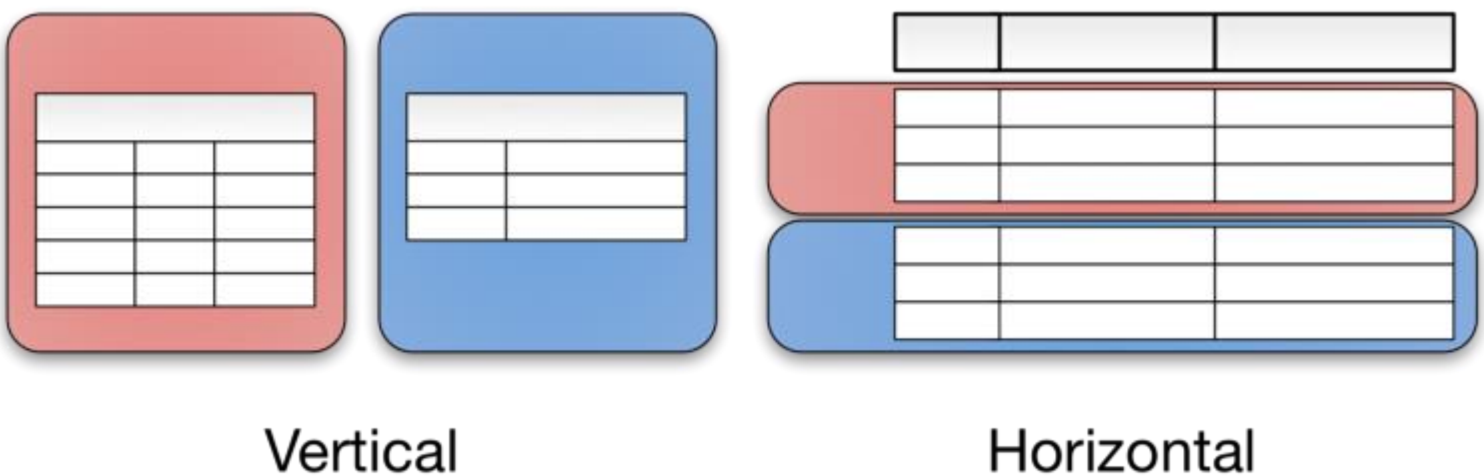
- Bigger servers
- Lots of little boxes in massive grids



Parallelism is not natural for relational databases

- Vertical: normalization, splitting into smaller tables
- Horizontal: splitting single table into multiple sets of rows

- SQL designed to run as a single node
- Both vertical partitioning and horizontal partitioning introduce performance bottlenecks



History

1980

Relational databases

1990

2000

NoSQL databases

2010

Aggregate databases:

Key-value
Document
Wide-column

Graph databases

String databases

Future?

1980

Relational databases

1990

2000

NoSQL databases

2010

Polyglot persistence

When to use RDBMS

- Fast application development
- Data integrity and security is important
- Loss of data is unacceptable
- Concurrent data modification: by multiple users
- Data can be easily modeled as relations

When to consider alternative data stores

- String databases
- Audio, video databases
- Document databases
- Graph databases

Many facets of Database studies

- Logical design
  - What kinds of information to store?
  - How to *model* data?
  - How are data items connected?
- Database programming
  - How does one express queries on the database?
  - How is database programming combined with conventional programming?
- Database system implementation
  - How does one build a DBMS

In this course we explore database world from the point of view of:

Designer

Developer

User

Textbook

"Database Systems: The Complete Book"

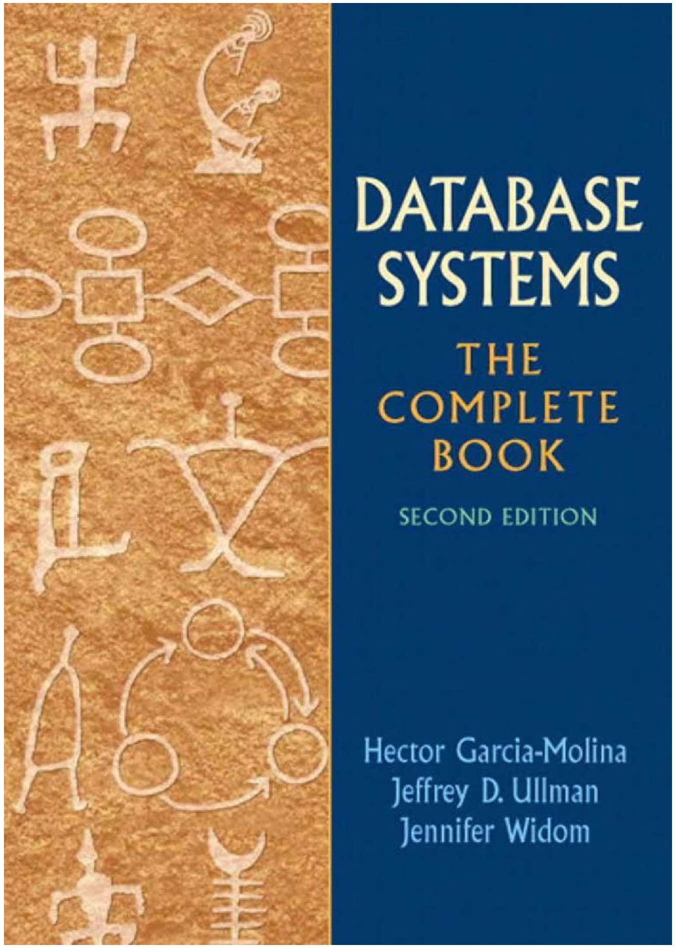
by *H. Garcia-Molina,*

J. D. Ullman,

and J. Widom,

2nd Edition.

Parts I and II and some topics from Part IV



Deliverables

- Weekly homeworks: 30%
- Midterm exam: 10%
- Final project: 30% *
- Final exam: 30% *

*You need to score at least 50% on the final project and on the exam in order to pass the course

Google classroom

- Class code: mj2w0h

Sample DBMSs used in this course

- SQLite
- PostgreSQL
- Spark on IBM datascientist workbench:

https://datascientistworkbench.com/

You have to know how to program in Java and Python